Illinois Department of Transportation

Memorandum

To: ALL BRIDGE DESIGNERS 02.3

From: Ralph E. Anderson Ralph E. Anderson

Subject: AASHTO LRFD – Design Policy Deck Slab and Slab Bridge Design

Date: October 4, 2002

All new bridges, with TS&L Plans submitted after October 1, 2007 have to be designed in accordance with AASHTO LRFD Design Specifications. For training and evaluation purposes, the superstructures of approximately 24 bridges have been designed by the LRFD Design Specifications. These designs have given us the tools to proceed with the final stage of implementation.

In order for the Illinois Department of Transportation to have a timely and smooth transition to the new LRFD Specifications, the Standards and Specifications Unit is in the process of setting policy and developing new LRFD manuals. To keep all designers abreast of these developments, this Bureau will be issuing a series of ALL BRIDGE DESIGNERS (ABD) memos prior to the completion of the manuals. To maintain consistency, all inquiries related to the implementation of the LRFD Design Specifications and for bridges outside the constraints stated in this memo should be directed to this unit.

To simplify the design of all multi-beam typical bridges in Illinois defined below, and to minimize the engineering efforts expended on these designs, the following criteria shall be considered:

- Two or more lanes should be used for design. This includes stage construction.

- Only the interior beam distribution should be used when overhangs are equal or less than the limits described below.

Typical multi- beam bridge is defined as:

- At least (5) beams
- 7.5” minimum slab thickness
- Beam spacing between 3.5 ft. and 12 ft.
- Span lengths between 20 ft. and 240 ft.

Overhang Limits are:

- 3'-8" for concrete parapets and curb mounted steel railing
- 2'-5" for Type S-1 Railing
- 2'-1" for Type SM Railing

Also included in this memo are only portions of the articles of Section 3.2 of the current Bridge Manual that have been modified for incorporation in the new LRFD Bridge Manual. This covers deck slab on girder design procedures, new design charts for deck reinforcement, new deck details for overhangs at fascia girders and slab bridge design details. These modifications are based on the 1998 AASHTO LRFD Bridge Design Specifications with 1999 through 2002 Interims.

SYK/WAB/24174

Concrete Deck Slabs on Girders

Concrete deck slabs supported on stringers shall be designed in accordance with Articles **3.6.1, 4.6.2.1.1-7, 5.5.4.2.1, 5.7.3, 5.10.8.2 and 9.7.3 of the AASHTO LRFD** Specifications as noted. **Figure 1 and Appendix 1** may be used in lieu of complete computations. These figures are applicable to the design of slabs on steel or prestressed concrete girders and also to the transverse design of the slab portion (flange portion) of reinforced concrete deck girder (T-Beam) superstructures.

Defined in **Figure 1 and Appendix 1** are the design span, reinforcement clearances and design stresses to be used in slab design. An allowance of 50 psf and 25 psf for future wearing surface is included in the criteria for **Figure 1 and Appendix 1**, respectively. All supporting elements of structures shall be designed using an allowance of 50 psf. **Appendix 1** may be used for existing structures when necessitated by limited load carrying capacity.

Figure 1 and Appendix 1 were developed by using the following design assumptions and equations. Design spans or loads outside the range covered by these charts require individual computations using this same criteria. Also, designs utilizing reinforcement sizes other than #5 bars require individual computations.

Design Criteria

A. Design Stresses

Concrete $f_c' = 3.5$ ksi

Reinforcement $f_y = 60$ ksi

B. Loading

Live Load – HL – 93 (3.6.1.2.1 – 5 and 3.6.1.3.3)

Live Load Moment – LRFD Appendix A4

Dead Load

Self – weight of slab (DC) plus allowance for FWS (DW)

$$\text{Dead Load Moment} = M_{DC\,or\,DW} = \frac{wS^2}{10}$$

$$\text{Factored Design Moment} = M_{FL} = \eta_D \eta_R \eta_I \left[1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+I}\right] \text{(Tbls 3.4.1-1 \& 2)}$$

Load Modifiers η_D, η_R, η_I are all unity for typical bridges (1.1.3 - 5)

C. Design Thickness

To insure adequate reinforcement clearances, the minimum slab thickness shall be 7.5 inches.

Design Criteria (continued)

D. Design Procedure and Equations

Assumptions

Sufficient reinforcing steel must be provided to satisfy each of the following criteria :

1. Ultimate Strength – Strength Limit I (5.7.3.2)
2. Distribution of Reinforcement – Service Limit State I (5.7.3.4)
3. Maximum Reinforcement (5.7.3.3.1)
4. Minimum Reinforcement (5.7.3.3.2)

1. Ultimate Strength, $M_r = \phi M_n$

$$M_r = \phi\left[A_s f_y d_s\left(1-0.6\rho\frac{f_y}{f_c'}\right)\right] \geq M_{FL} \text{ (Factored Design Moment)}$$

where: M_r = Factored Resistance (k – ft per ft)

$\phi = 0.9$ (5.5.4.2.1)

f_y = Specified yield strength of reinforcement (ksi)

d_s = Distance from extreme compression fiber to centroid of tensile reinforcement (in)

A_s = Area of tension reinforcement (in^2 per ft)

f_c' = Specified compressive strength of concrete (ksi)

b = Width of design strip (in)

$$\rho = \frac{A_s}{bd}$$

2. Distribution of Reinforcement

$$f_{sa} = \frac{Z}{\sqrt[3]{d_c \times A_{eff}}} \leq 0.6 f_y$$

$$f_s = \frac{M_s}{A_s \times j \times d_s} \leq f_{sa}$$

where: f_{sa} = allowable tensile stress in the reinforcement at service loads (ksi)

f_s = calculated tensile stress in reinforcement due to service loads (ksi)

M_s = applied moment due to service loads (k - ft per ft)

Z = crack width parameter (130 kips / in)

d_c = depth of concrete from extreme tension fiber to center of bar. Clear Cover used for calculation purposes shall not exceed 2 in.

A_{eff} = effective tension area of concrete surrounding the main tension reinforcing bars having the same centroid as that of reinforcment, divided by the number of bars. The vertical bounds of the area are a line parallel to the neutral axis and the cross sectional surface. Clear cover used for calculation purposes shall not exceed 2 in.

Design Criteria (continued)

3. Maximum Reinforcement shall be limited to :

   $\rho_{max} = 0.0175$ for $f_c^{'} = 3.5$ ksi and $f_y = 60$ ksi

4. Minimum Reinforcement,

   The amount of tensile reinforcement shall be adequate to develop a factored flexural resistance, M_r, at least equal to the lesser of :

   1) $1.2M_{cr}$ or

   2) $1.33M_{FL}$

where : $M_{cr} = \dfrac{f_r \times I_g}{y_t}$

Longitudinal steel in top of slab = #5 bars at 12'' cts. plus additional steel over piers.
Longitudinal steel in bottom of slab = 67% of the main bottom reinforcement.

See Figure 2 for Design Span, S, Definitions.

Example

Given: Beam Space = 7'-0'', b_f = 12'' (Steel Beam)
S (Bottom Reinforcement) = 7.0'
S (Top Reinforcement) = 7-½(1') = 6.5'
Enter chart at S = 7.0' and project line vertically to bottom reinforcement line. Then project horizontally to get required spacing for bottom reinforcement, #5 @ 9''cts.
Enter chart at S = 6.5' and project line vertically to top reinforcement line. Then project line horizontally to get required spacing for top reinforcement, #5 @ 6½'' cts.

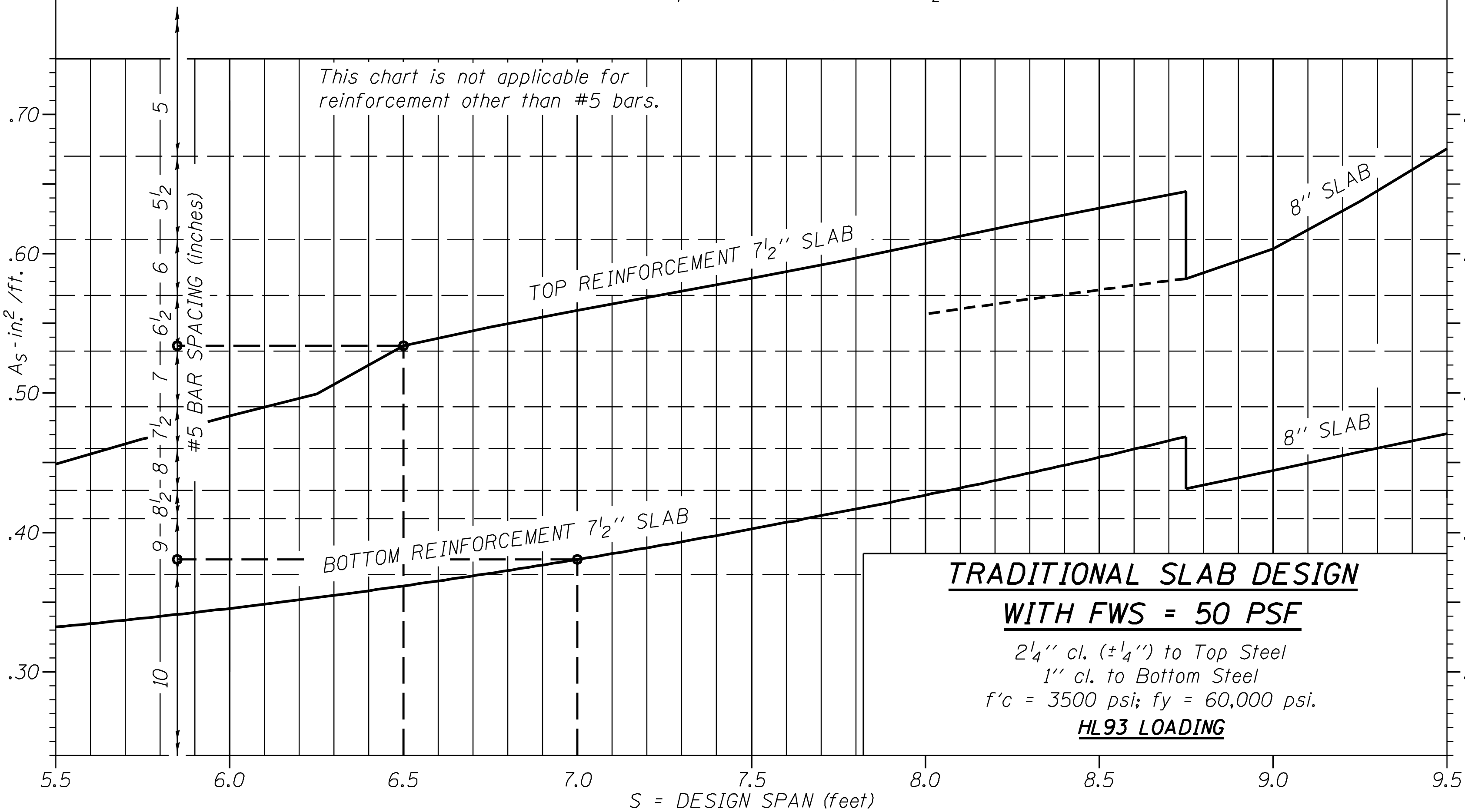


Figure 1

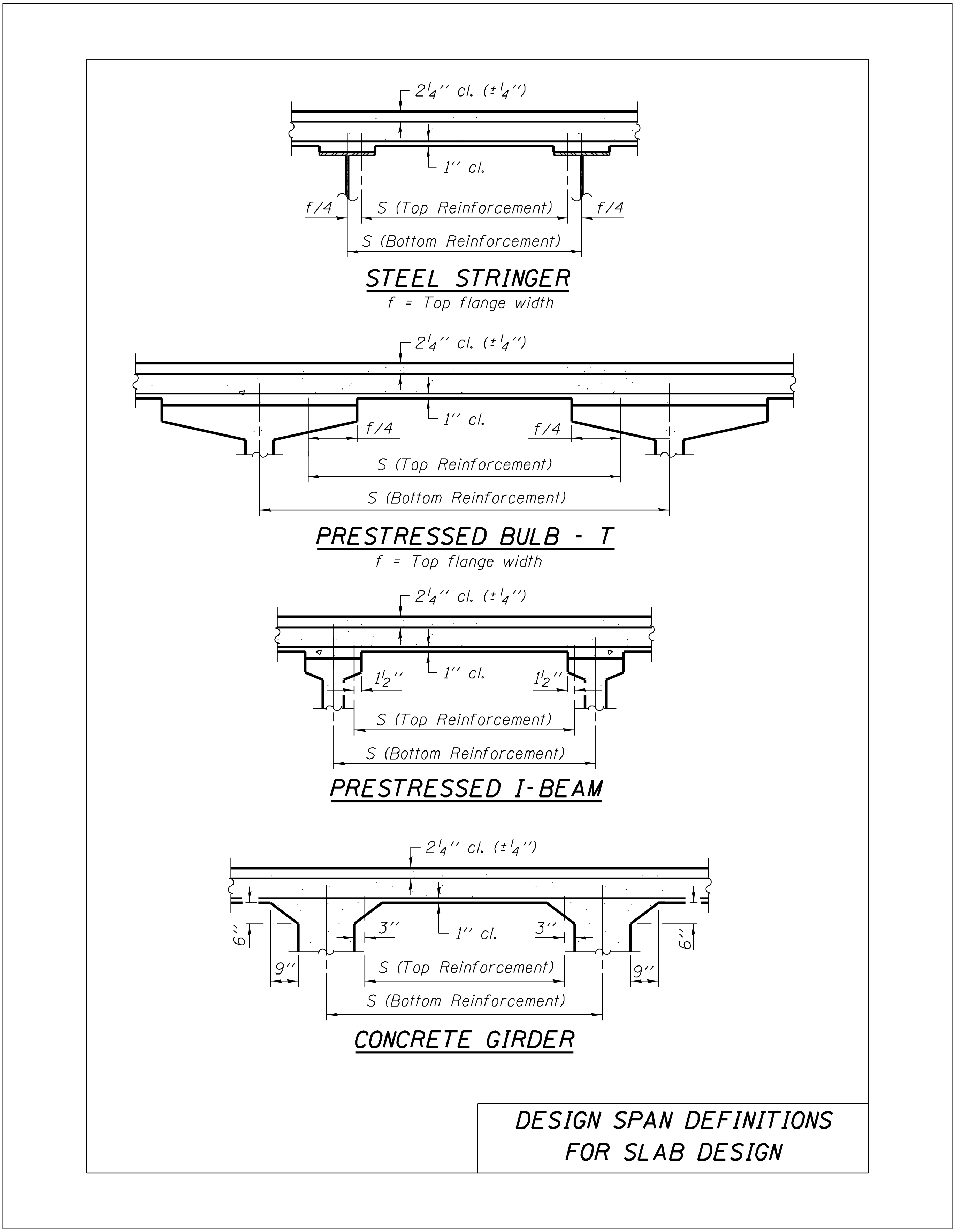

2¼" cl. (±¼")
1" cl.
f/4
S (Top Reinforcement)
f/4
S (Bottom Reinforcement)
STEEL STRINGER
f = Top flange width
2¼" cl. (±¼")
1" cl.
f/4
f/4
S (Top Reinforcement)
S (Bottom Reinforcement)
PRESTRESSED BULB - T
f = Top flange width
2¼" cl. (±¼")
1½"
1" cl.
1½"
S (Top Reinforcement)
S (Bottom Reinforcement)
PRESTRESSED I-BEAM
2¼" cl. (±¼")
6"
3"
1" cl.
3"
6"
9"
S (Top Reinforcement)
9"
S (Bottom Reinforcement)
CONCRETE GIRDER
DESIGN SPAN DEFINITIONS
FOR SLAB DESIGN

Figure 2

Reinforcement (Deck Slabs on Girders)

Truss bars shall not be used in bridge decks. The maximum size bars permitted in the slab for transverse reinforcement is #6. However, **Figure 1 and Appendix 1** are based on #5 bars. If #6 bars are used, they must be designed by computation. Do not mix bar sizes, such as #5 and #6 to provide main reinforcement; use one bar size properly spaced. The spacing shall be to an even one-half inch. **The maximum spacing, for top and bottom transverse bars shall be 10".**

AASHTO **LRFD 9.7.3.2** presents the criteria for distribution reinforcement in the bottom of slabs when the main reinforcement is perpendicular to the direction of traffic. In effect, it states that for design spans up to about 11'**,** the distribution shall be sixty-seven (67) percent of the main bottom reinforcement in the slab. The bottom longitudinal distribution reinforcement shall be #5 bars and the maximum spacing shall be 15". **This limit is based on the maximum spacing for transverse bars.**

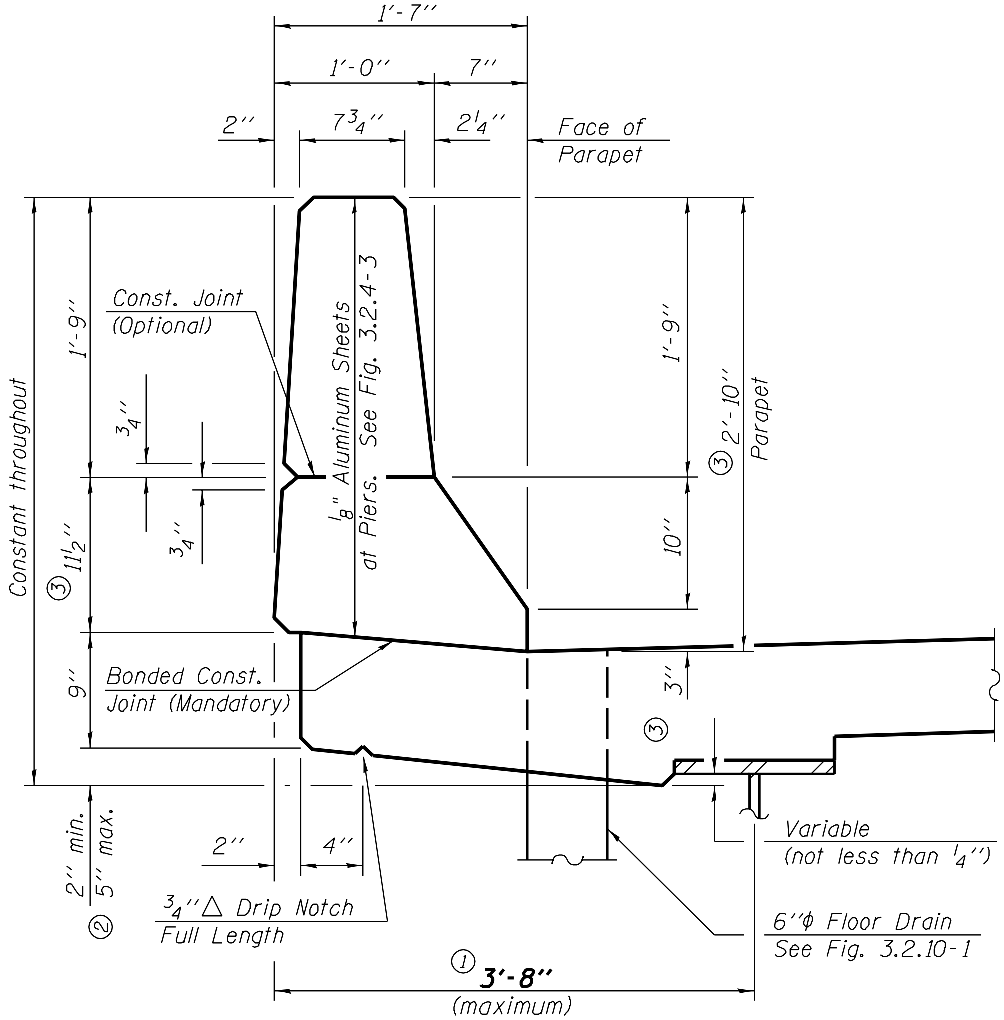
Except as shown in **Figure 1 and Appendix 1** for Bulb-T's, no distribution steel shall be placed directly over a girder; the reinforcement shall be equally spaced between the edge of the girder flanges with the first bar approximately 4" from the edge. For instance, if 0.61 in^2 per ft is required for the main bottom reinforcement in the slab, then #5 at 6" centers would be satisfactory and 0.67(0.61)=0.41 in^2 per ft would be required for the distribution steel. This area could be furnished by #5 at 9" centers, spaced as described above between the flange edges. Indicate the bar spacing (such 8-#5 bars at 9"cts.); do not call for "8 bars at equal spacing".

The longitudinal bars in the top of the slab shall be #5 at 12" centers placed full width of the superstructure **in order to satisfy temperature and shrinkage requirements of Art. 5.10.8.2.**

The top and bottom longitudinal bars shall not be lapped in the same locations in the deck, nor shall the top and bottom transverse bars be lapped in the same locations except when staged construction is utilized.

On continuous structures which are non-composite over the piers, additional reinforcement shall be provided in the top of the slab for negative reinforcement over the piers. Between the normal #5 at 12" centers, #6 bars spaced at 12" centers shall be placed over the piers for the full width of the superstructure, including the top of the slab under the parapet base. (See **Figure 4**).

Note: All edges shall have ¾″ chamfer.



① When superstructure is curved and stringers are straight, the minimum allowable overhang is 1′-3″. Actual maximum and minimum dimensions are to be shown on plans. See Prestressed Concrete Manual for limitations with Bulb-T's.

② When more than 5″ is required add excess to 9″ dimension.

③ Add 2″ when initial Waterproofing Membrane System and Wearing Surface is used.

CONCRETE PARAPET CONFIGURATION

Figure 3

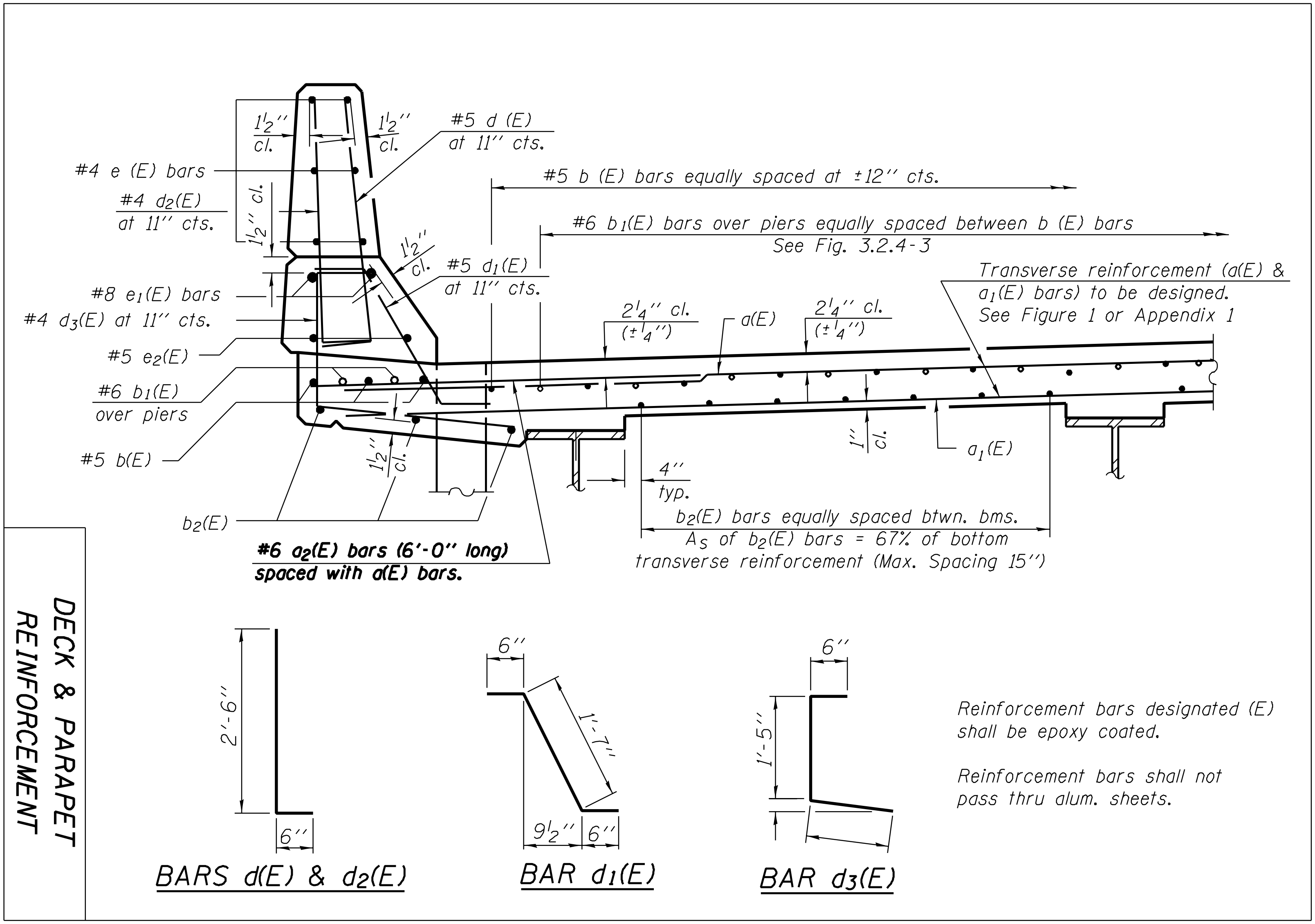

DECK & PARAPET REINFORCEMENT
1½'' cl.
1½'' cl.
#5 d (E) at 11'' cts.
#4 e (E) bars
#4 d2(E) at 11'' cts.
1½'' cl.
1½'' cl.
#5 b (E) bars equally spaced at ±12'' cts.
#6 b1(E) bars over piers equally spaced between b (E) bars
See Fig. 3.2.4-3
#5 d1(E) at 11'' cts.
#8 e1(E) bars
#4 d3(E) at 11'' cts.
#5 e2(E)
#6 b1(E) over piers
#5 b(E)
Transverse reinforcement (a(E) & a1(E) bars) to be designed.
See Figure 1 or Appendix 1
2¼'' cl. (±¼'')
a(E)
2¼'' cl. (±¼'')
1'' cl.
a1(E)
1½'' cl.
4'' typ.
b2(E)
b2(E) bars equally spaced btwn. bms.
As of b2(E) bars = 67% of bottom transverse reinforcement (Max. Spacing 15'')
#6 a2(E) bars (6'-0'' long) spaced with a(E) bars.
2'-6''
6''
BARS d(E) & d2(E)
6''
1'-7''
9½''
6''
BAR d1(E)
6''
1'-5''
BAR d3(E)
Reinforcement bars designated (E) shall be epoxy coated.
Reinforcement bars shall not pass thru alum. sheets.

Figure 4

Slab Bridges - Main Reinforcement Parallel to Traffic

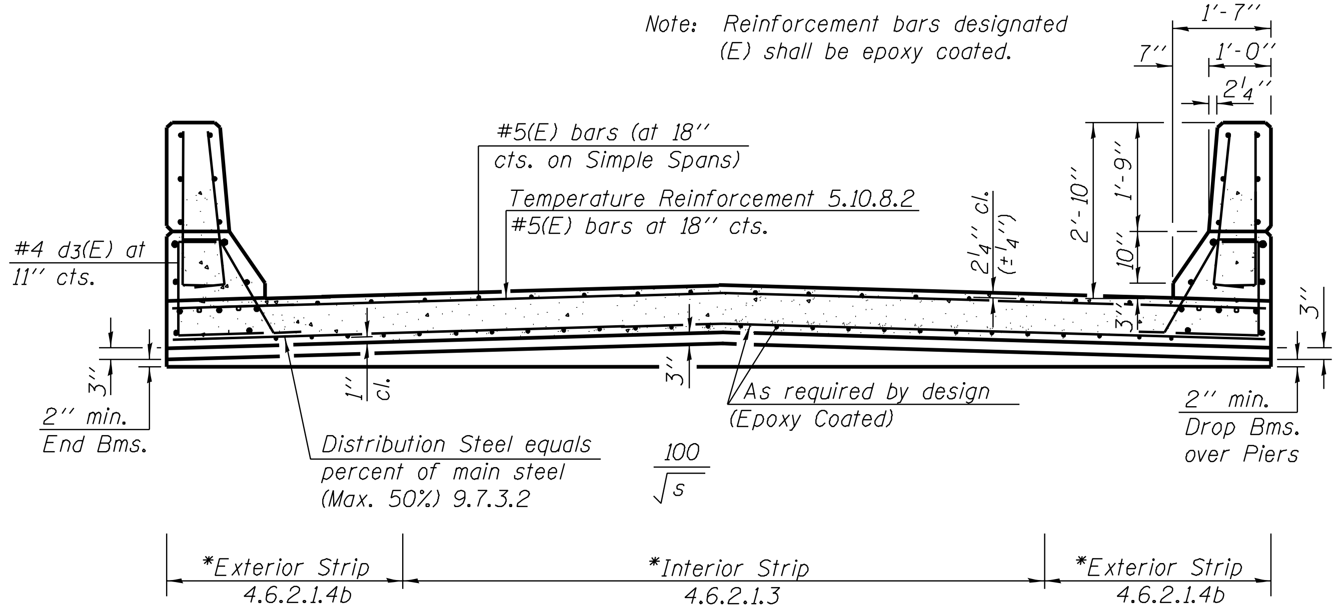
Figures 5 through 7 present details and the general placement of reinforcement for slab superstructures. **Slab bridge decks are divided into interior and exterior strips according to AASHTO LRFD Articles 4.6.2.1.3 and 4.6.2.1.4b, respectively. The controlling case (i.e. interior or exterior strip) shall be the design for the entire width of the superstructure.**

The minimum concrete bridge slab thickness requirements of **LRFD Table 2.5.2.6.3-1** shall not be applicable to concrete slabs that meet the requirements for Fatigue **(Article 5.5.3.2)** and Crack Control **(Article 5.7.3.4).**

Transverse bottom of slab Distribution Steel is specified in Art. 9.7.3.2 as a percentage of the positive moment reinforcement running parallel to the direction of traffic. Temperature and shrinkage steel shall conform to Art. 5.10.8.2.

If the out to out width of the superstructure exceeds 45'-0", an open longitudinal joint as shown in Figure 5 is required. However, if staged construction is utilized, the joint may not be necessary. Consult the Bureau of Bridges and Structures when this situation arises.

Figure 5

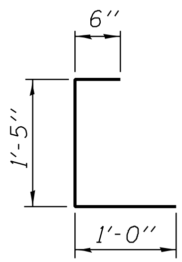


HALF SECTION

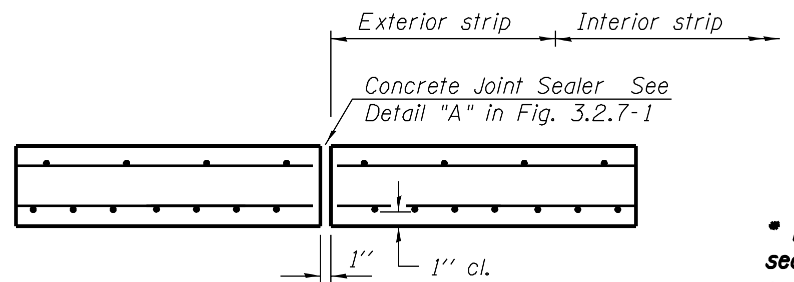
Simple Spans or Midspan of Continuous Spans

HALF SECTION

Near Pier of Continuous Spans



BAR d3(E)



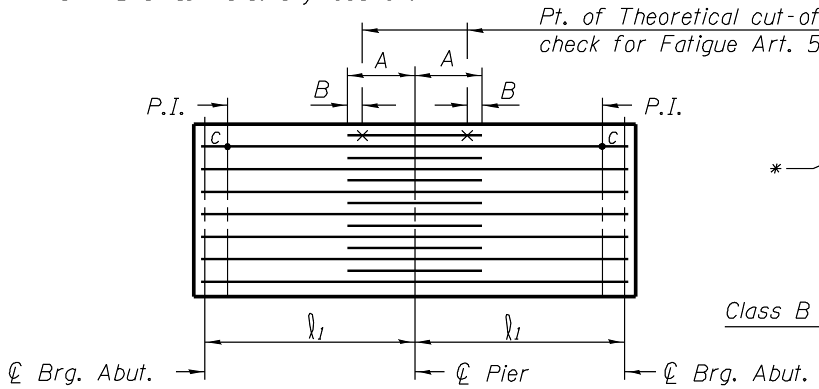
DETAIL AT OPEN JOINT

*** Design entire cross section for controlling case.**

SLAB BRIDGES

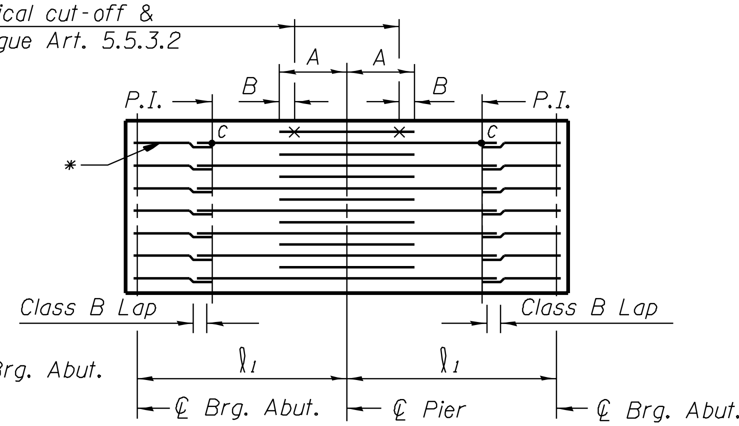
Figure 6

* Note: Top reinforcement bars no less than #5 at 18'' cts. any location.



REINF. IN TOP OF SLAB ($\ell_1 \le 18'$)

(Use same size bars, or two sizes where long bars are not less than $^1{}_3$ A_S. A_S = Total Neg. Moment steel area.)



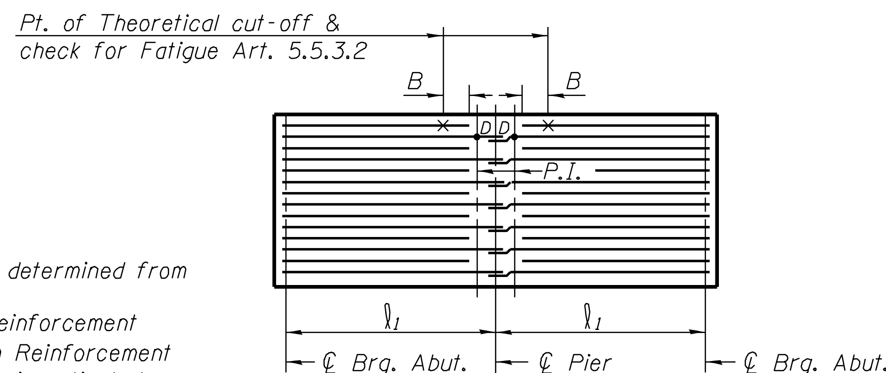
REINF. IN TOP OF SLAB ($\ell_1 > 18'$)

(Use same size bars, or two sizes where long bars are not less than $^1{}_3$ A_S. A_S = Total Neg. Moment steel area.)

REFERENCE TO AASHTO:

A - Article 5.11.1.2.1 & 5.11.2
B - 5.11.1.2.1
C - 5.11.1.2.3
D - 5.11.1.2.2

Notes: P.I. - The point of Inflection as determined from the applied Moment Envelopes of
D + [-(L + I)] for Top Reinforcement
D + [+(L + I)] for Bottom Reinforcement
Max. Reinf. Stress range shall be investigated at section of stress reversal Art. 5.5.3.2



REINF. IN BOTT. OF SLAB

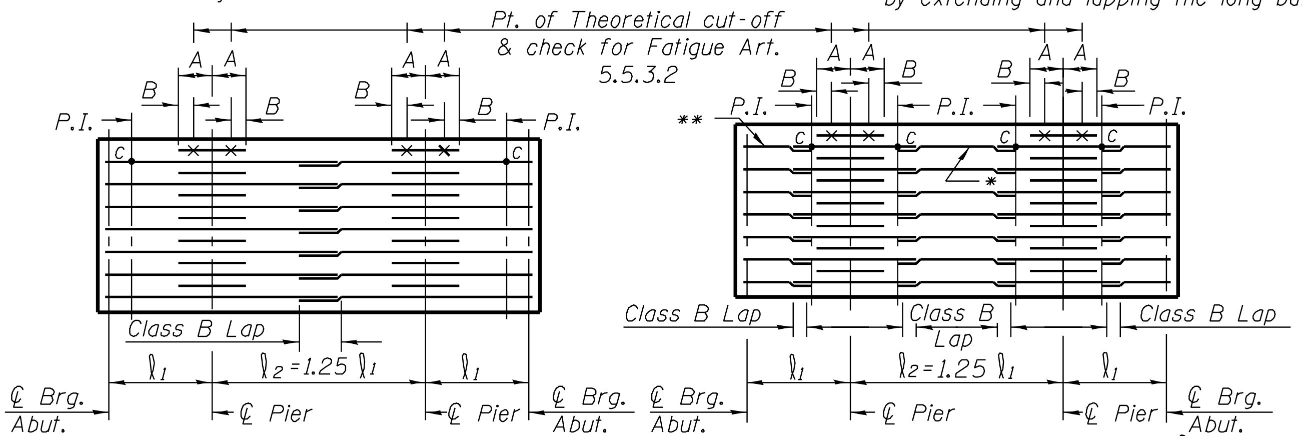
(Use same size bars)

TWO SPAN
SLAB BRIDGES

Figure 7

** Note: Top reinforcement bars no less than #5 at 18'' cts. any location.

* As an alternate these bars may be omitted by extending and lapping the long bars.

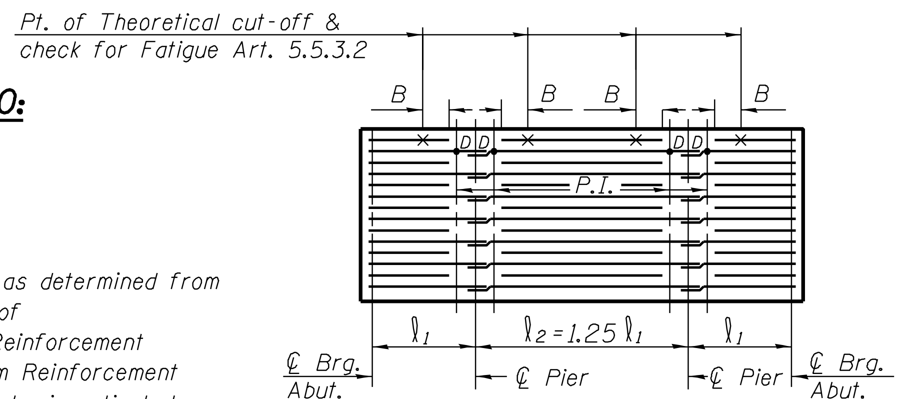


REINF. IN TOP OF SLAB ($\ell_1 \leq 20'$)

(Use same size bars, or two sizes where long bars are not less than $^1\!/_3$ A_S. A_S = Total Neg. Moment steel area.)

REINF. IN TOP OF SLAB ($\ell_1 > 20'$)

(Use same size bars, or two sizes where long bars are not less than $^1\!/_3$ A_S. A_S = Total Neg. Moment steel area.)



REINF. IN BOTT. OF SLAB

(Use same size bars)

REFERENCE TO AASHTO:

A - Article 5.11.1.2.1 & 5.11.2
B - 5.11.1.2.1
C - 5.11.1.2.3
D - 5.11.1.2.2

Notes: P.I. - The point of Inflection as determined from the applied Moment Envelopes of
D + [-(L + I)] for Top Reinforcement
D + [+(L + I)] for Bottom Reinforcement
Max. Reinf. Stress range shall be investigated at section of stress reversal Art. 5.5.3.2

THREE SPAN
SLAB BRIDGES

Appendix 1

Longitudinal steel in top of slab = #5 bars at 12″ cts. plus additional steel over piers. Longitudinal steel in bottom of slab = 67% of the main bottom reinforcement.

See Figure 2 for Design Span, S, Definitions.

Example

Given: Beam Space = 7′-0″, b_f = 12″ (Steel Beam)
S (Bottom Reinforcement = 7.0′
S (Top Reinforcement) = 7-½(1′) = 6.5′
Enter chart at S = 7.0′ and project line vertically to bottom reinforcement line. Then project horizontally to get required spacing for bottom reinforcement, #5 @ 9″cts.
Enter chart at S = 6.5′ and project line vertically to top reinforcement line. Then project line horizontally to get required spacing for top reinforcement, #5 @ 7″ cts.